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The solar thermal market in Greece—review and perspectives

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Abstract

The Hellenic solar thermal market is actually one of the most developed worldwide. This paper provides an overview of the evolution of this market since its start in the mid-1970s until today. The reasons for its success are discussed in detail: the role of the manufacturers, the quality assurance practices applied and the incentives on the demand and supply sides. The role of economic instruments towards the development of the Hellenic solar thermal market is investigated using a cost–benefit analysis (CBA). Although commercially successful, solar thermal applications today in Greece still cover a very limited percentage of their potential applications. The perspectives and potential barriers for their future development are presented, analyzed by a CBA and discussed. This information is useful for all parties related to this market, manufacturers, potential users, policy makers, etc. Countries having a solar energy potential similar to that of Greece but a less developed solar market may also identify in this work parameters that will contribute to the development of their national market.

Contents

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1. Introduction

The Hellenic market of solar thermal systems is one of the most successful worldwide. The aim of this paper is to point out the key technical, financial and policy related elements that contributed to this success story and to discuss the perspectives for its further development. This information is useful for all parties related to this market, manufacturers, potential users, policy makers, etc. The European Commission in its communication entitled “Energy for the Future: Renewable Sources of Energy” [1] incites the EU member states to follow the examples of Austria, Germany and Greece in the field. Countries with a solar energy potential similar to that of Greece having a less developed solar market may also identify in this work parameters that will contribute to the development of their national market.

First, a review of the solar thermal market in Greece is presented, starting from the mid-1970s when the systematic sales of individual solar systems began, until today. This retrospective is classified in phases; the basic features of each phase are discussed and the reasons for the market changes during the particular phase are pointed out. A comparison with the markets of other European countries is also given. Technical, manufacturing and quality control issues of the Hellenic thermal solar industry are provided.

This is followed by a presentation of the organization of the Hellenic solar thermal industry. The role of the Hellenic Solar Industry Association is emphasized, since, as it will be explained, its creation appears to have played a key role to the improvement of the quality of the products and services offered. This Association was also the precursor of the European Solar Industry Federation (ESIF).

The financial incentive schemes on the demand and supply sides applied in Greece and their effectiveness are presented in detail in together with information regarding major solar thermal applications.

Table 1
Key indicators of Greece (IEA, 1998)

Population (million)	10.51
Total primary energy supply (Mtoe)	26.98
TPES/population (toe/capita)	2.57
Electricity consumption/population (kWh/capita)	4261
GDP (US$ 1990 billion)	96.72
Electricity consumption (TWh)	44.77
TPES/GDP (toe/$ 1000)	0.28
Electricity consumption/GDP (kWh/$)	0.46

Finally, the future prospects and the evaluation of barriers of the Hellenic solar thermal market are discussed and suggestions for further development are made. Emphasis is given to the residential sector, since this contributes significantly to the energy budget of the country and has such energy needs that match well the possibilities offered by solar thermal systems.

Some key data regarding the country and its energy consumption, as of 1998, are presented in Table 1 and Fig. 1. It can be seen that despite the successful domestic solar thermal market, the contribution of this technology to the national energy

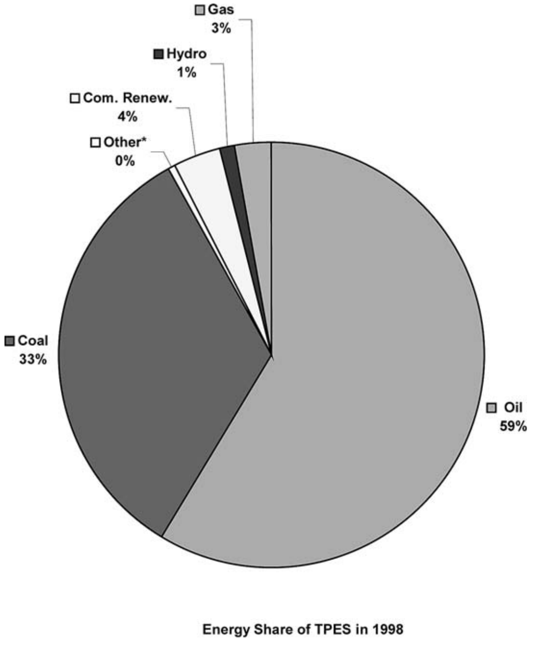

Fig. 1. Greece—key energy indicators in 1998 (IEA, 1998). (*Notes*: (1) Electricity trade is excluded from the graph. (2) Com. Renew. comprises solid biomass and animal products, gas/liquids from biomass, industrial waste and municipal waste. Data are often based on partial surveys and may not be comparable between countries. (3) Solar thermal is included in the category Other.)

budget is extremely small. Therefore the potential for further market development in terms of potential applications is far from being negligible.

2. Solar thermal market in Greece

2.1. Trends

A survey of the Hellenic solar thermal market reveals several phases that could be classified as follows:
Phase A: Starts in 1975 when the first massive sales of solar thermal collectors began and ends in 1984. During that period, the sales increased steadily due to the oil and currency crises and the adoption of tax incentives in favor of solar systems.

Phase B: Covers the period from 1984 to 1986. The sales were really boosted as a result of a large advertising campaign sponsored by the Hellenic government and also because of the fear that the application for the first time of the value added tax (VAT) in the Hellenic economy by January 1st, 1987, would increase the consumer prices [2].

Phase C: From 1987 to 1993, when the market remained practically stable and then decreased. The stability of the Hellenic market during that period compared to the market collapse elsewhere, was due to its already important size and also to the quality and efficiency of the solar thermal products that had improved significantly meanwhile [3]. Again, a large-scale advertising campaign, financed by the Hellenic Solar Industry Association and the "Organization for the Promotion of Hellenic Products" (an agency for promoting exports), improved the image of solar thermal systems. The tax deduction incentive was maintained at the beginning of this phase but waved later on. The constantly increasing cost of electricity, the application of the VAT and the continuous devaluation of the national currency, maintained the solar thermal systems at the top three positions of the demand of constant consumer products.

Despite the constantly improving quality and efficiency of the solar thermal systems, the market started deceasing after a while. Several factors contributed to this.

- Financial constraints that slowed down the rate of construction of new buildings and the fading out of the effects of the previous oil crisis.
- Governmental interventions that kept the tariffs of electricity low as the result of "social policy" (the electricity production was a state monopoly).
- All financial incentives in favor of solar systems were gradually withdrawn.
- The solar thermal industry did not allocate an appropriate budget for promotion campaigns.

Phase D: From 1994 until this date. The solar thermal market has become practically stable. In 1999 from the 420 000 m^2 of glazed collectors sold in Europe, 50% was sold in Germany. Greece followed with 160 000 m^2, amounting to the market share of 18% on the European level [4].

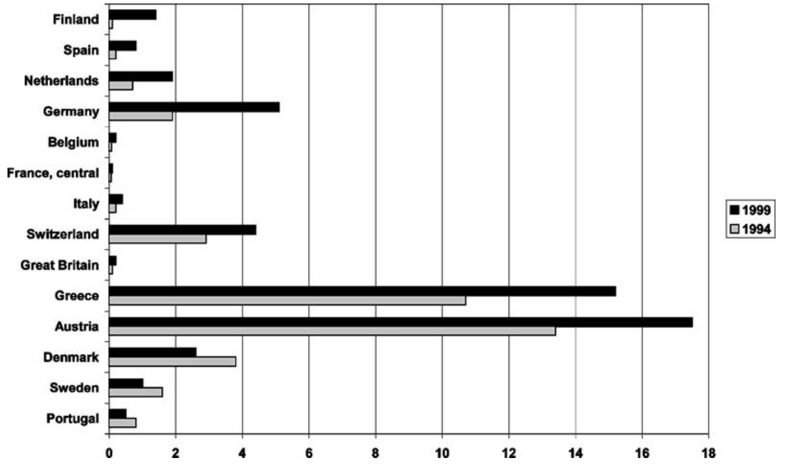

Fig. 2. Installed glazed collector area per 1000 inhabitants in European countries from 1994 to 1999 (ascending order by market growth) (Deutscher Fachverband Solarenergie e.V., [4]).

Fig. 2 provides an overview of the installed collector area in several European countries between 1994 and 1999. It is observed that countries like Greece and Austria, which were relatively high ranked in 1994, increased their market during this period by 8 and 6%, respectively, while Italy and Spain, exceeded these rates by achieving a 50 and 74% of annual growth.

The sales and exports of solar collectors in Greece between 1989 and 1999 are illustrated in Fig. 3. The impact of a systematic export effort that started in 1991 is clearly shown. Despite some pessimistic forecasts that appeared in several studies in the past, the Hellenic industry succeeded to penetrate all markets considered as

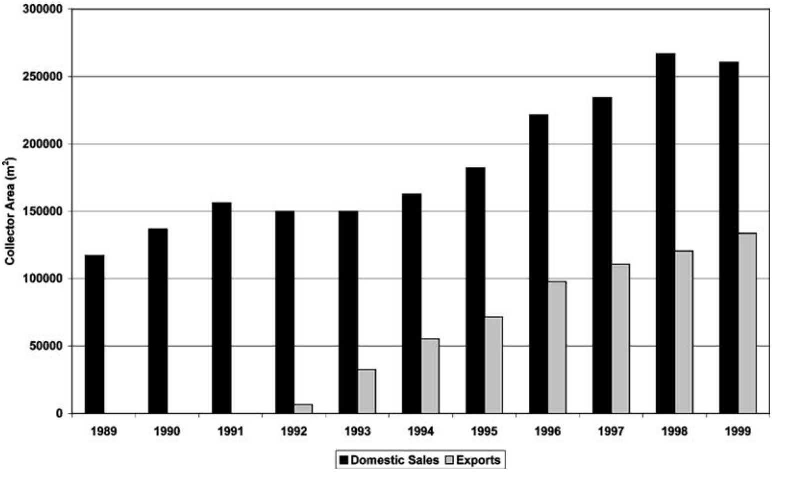

Fig. 3. Sales and exports of Greek solar collectors (EBHE, [3]).

difficult, namely those of Germany, Austria, Cyprus, Israel and Turkey. Today the Hellenic solar thermal systems can be found in many countries worldwide, including in South Africa and Indonesia. A fact demonstrating the important export potential of the industry is that the Greek systems cover actually the 60% of the German market, which is the biggest market of today.

2.2. Typologies and applications

More than 95% of the installed collector area is used in natural circulation domestic hot water (DHW) solar systems. These are closed loop systems (in their vast majority), using antifreeze (glycol solution) as a heat transfer medium. The storage tank, horizontal or vertical, is positioned above the collectors. The average size of the natural circulation systems sold, has 2.5 m^2 of collector area and a 150-l storage tank. The most commonly used systems have a collector area of 1.8–4 m^2 and the volume of the storage tank ranges between 120 and 220 l, respectively. There are also several types of integral collector storage systems and compact systems.

All systems use an electrical resistance as a backup-heating source. Only 3% of them have an additional heat exchanger connected to the space heating system (usually a diesel burner central heating system).

The average annual solar fraction usually exceeds 75%, depending on the geographical location of the system. Test results of solar thermal components and systems revealed that their annual energy output ranges from 350 to 800 kWh m^{-2}. This value depends greatly on the daily and seasonal hot water consumption profile of the user.

2.3. Product technology and production methods

Most of the manufacturers have developed their own technology for flat plate collectors, which is similar to that used in other countries. However, specific parts like selective absorption coatings are imported. The techniques used for the various components of flat plate collectors and/or their characteristics are summarized in Table 2 [2].

The breakdown of an average size natural circulation DHW system, based on actual retail prices, is given in Table 3 [2]. This average breakdown estimation does not apply for all industries. This is due to differences in the product mix, production capacity and methods, and the distribution and sales methods.

2.4. Quality assurance

Although the compliance of solar thermal products to specific standards is not enforced in Greece, advanced quality assurance standards are applied in practice. As soon as the major manufacturers established the Hellenic Solar Industry Association (EBHE) in 1978, testing and certification of thermal solar systems became a prerequisite for being a member of the Association. Thus the reputation of solar thermal systems was preserved despite the often-faulty technology installed in the early years

Table 2
Manufacturing techniques/characteristics of flat plate collector components (ESIF, [2])

Component description	Technique/characteristic
Collector area (m^2)	1.5–8
Absorber material	Steel or stainless steel roll bond
	Aluminum or copper bonded on copper or galvanized steel tubes
	Copper bonded on copper tubes
	Copper welded or soldered on copper tubes
Absorber surface	Black paint
	Selective paint
	Selective coating
Insulation	Many types e.g.:
	30 mm glasswool
	70 mm of rockwool combined to hard polyurethane (CFC free)
Transparent cover	Normal window-type glass (3–4 mm)
	Solar tempered glass (3–4 mm)
	Plastic
Casing	Extruded aluminum (anodized or with polyester paint)
	Formed aluminum or steel sheet
	Various plastics
Storage tank material	Steel with internal enamel or epoxy or other “plastic” coating
	Stainless steel
	Galvanized steel
Storage tank insulation	Polyurethane (40–70 mm)
Anticorrosion system	Cathodic protection
Storage tank cover	Aluminum
	Stainless steel
	Painted or galvanized steel
	ABS

Table 3
Cost breakdown of an average size natural circulation system for DHW (ESIF, [2])

Materials (%)	33
Labor (%)	11
Promotion and general expenses (%)	43
Installation cost (labor and materials) (%)	14

of solar energy applications. In the country there is only one laboratory accredited for collector testing according to EN 45001. This belongs to a governmental research center and provides the following services to the Greek solar industry:

- Efficiency tests for flat plate solar collectors according to ISO 9806-1.
- Qualification tests for flat plate solar collectors according to ISO 9806-2.
- Performance tests in solar domestic hot water systems according to ISO 9459-2.

In 2001, the Hellenic Standardization Organization (ELOT) has replaced the above standards with the following:

- ELOT EN 12975-1 and 2: thermal solar systems and components—solar collectors—general requirements and test methods.
- ELOT EN 12976-1 and 2: thermal solar systems and components—factory made systems—general requirements and test methods.
- ELOT EN 12977-1, 2, and 3: thermal solar systems and components—custom built systems—general requirements, test methods and performance characterization of stores for solar heating systems.

The electrical part of the storage tank is tested also according to the standards:

- ELOT EN 60335-1: electrical testing of household appliances.
- ELOT EN 60335-2: electrical testing of storage water heaters.

The imported equipment is not subjected to any mandatory testing in order to receive a marketing license.

2.5. The role of the economic instruments to the development of the Hellenic solar thermal market

It is widely recognized that economic instruments (i.e. subsidies, taxes, etc.) play a key role in the promotion of renewable energy sources worldwide. In this section, a cost–benefit analysis (CBA) from the consumer's perspective is undertaken, aiming to highlight the impact of the relevant implemented economic policies to the development of the Hellenic solar thermal market over the last 2–3 decades. Specifically, the economic attractiveness of DHW solar systems is examined comparatively, during the reference period, with respect to the presence or not of the implemented economic incentives.

CBA requires that all cost and benefit parameters are expressed in financial monetary terms and is based on specific decision-making rules similar to those applied in private-financial analysis evaluation [5]. The detailed stages of the calculation process are:

- *Definition of technological project parameters*. All the technical characteristics of the project under evaluation are recorded in detail. These may relate to capacity, efficiency, qualitative and quantitative characteristics of the inputs fed and the outputs produced, etc.
- *Determination of the project cost and benefit components*. The analysis involves initially the recording of the private cost and benefit components that determine the private-financial return of the project under study. These parameters can be easily determined from market data and previous experience. On the contrary, costs and benefits resulting from changes the variation in environmental quality or of other social goods are much more difficult to measure, especially when it

comes to non-tradeable goods such as human health, biodiversity preservation, depletion of natural resources, trend toward depletion, etc., and are not taken into account in the framework of this study.

- *Calculation of the present value (PV) of costs and benefits*. The time allocation of the cost and benefit components over the lifecycle of the project under study, greatly affects the analysis results. Following the determination of these factors over the whole time horizon of the analysis, it is possible to calculate their PV, using a suitable discount interest rate.
- *Quantitative estimation of financial evaluation indicators*. The indicators used in CBA are based on the criteria applied in private-financial analysis used for the financial evaluation of a project. These are the net present value criterion (NPV > 0), the internal rate of return criterion (IRR > 1) and the benefit–cost ratio criterion ($B/C > 1$).
- *Sensitivity analysis*. At this final stage an attempt is made to investigate the sensitivity of the evaluation analysis results to critical parameters presenting a high degree of uncertainty.

The economic analysis presented here has been performed for 5 years (1980, 1985, 1990, 1995 and 2000) that cover the development period of the solar thermal market in Greece. Table 4 summarizes the most important technological and economic parameters that influence the overall performance of the DHW solar systems under consideration [2,6]. The figures for solar radiation and water supply temperature that affect the efficiency of the system, are assumed to be close to the national averages [7]. The main changes identified during the period 1980–2000, are shortly summarized in the following:

The investment cost of the system slightly decreased during the 1980s as a result of technological improvements and remained practically the same during the 1990s.
The electricity tariffs have been significantly decreased in constant prices, especially during the last decade.
The national inflation rate has been dramatically decreased, especially during the last 5 years, affecting the consumer's behavior.

Table 4
Technical and financial data and assumptions for DHW solar systems (all costs referred to 1995 constant prices)

	1980	1985	1990	1995	2000
Investment cost (€)	1388	1050	944	944	944
Electricity conservation (kWh/system/y)	1440	1440	1440	1440	1440
Electricity cost (€/MWh)	116	123	120	88	80
Subsidies (€)	1092	574	94.4	94.4	94.4
Lifetime (years)	15	15	15	15	15
Discount rate (%)	18	18	18	9	6

The discount rates used in the analysis have been selected on the basis of a descriptive approach [8] resulting to figures that most people actually apply in their day-to-day operations and mostly reflect the marginal rate of return on investments, which prevails in a region during a specific time period. Particularly, during the 1980s, when the inflation rate in Greece was very high (above 20%) and the investments were characterized by high-risk premiums, the market-based discount rates were very high (in this analysis and for the consumer's behavior, a figure of 18% has been selected).

As clearly depicted in Fig. 4, the overall performance of DHW solar systems (without taking into account the various subsidies) has been considerably improved during the last two decades, while the implementation of specific economic incentives resulted significantly to their market penetration. More specifically, the B/C ratio of the reference systems was considerably lower than 1 during the early 1980s, while it reached a value around 1 during the second half of this decade. However, at the same period strong economic incentives were established aiming to facilitate the development of the solar market. These incentives covered a significant part of the system cost at that time improving its B/C ratio (from 0.72 to 3.40 in 1980 and from 1.01 to 2.24 in 1985), thus resulting to the market development. In the early 1990s, the market remained practically stable, since the improved B/C ratio of the systems as a result of the technological changes in the sector was compensated from the attenuation of the economic incentives policy. The implemented new subsidies improved only marginally the overall performance of the systems increasing the B/C ratio from 1.10 to 1.22. The same policy was retained during 1990s. However, the B/C ratio of the systems has been continuously improved due to the dramatically decrease of the inflation rates that affect the consumers behavior and the investment climate. Nowadays the DHW solar systems present a B/C ratio significantly higher than 1 and it seems that the market can be further developed even without economic incentives.

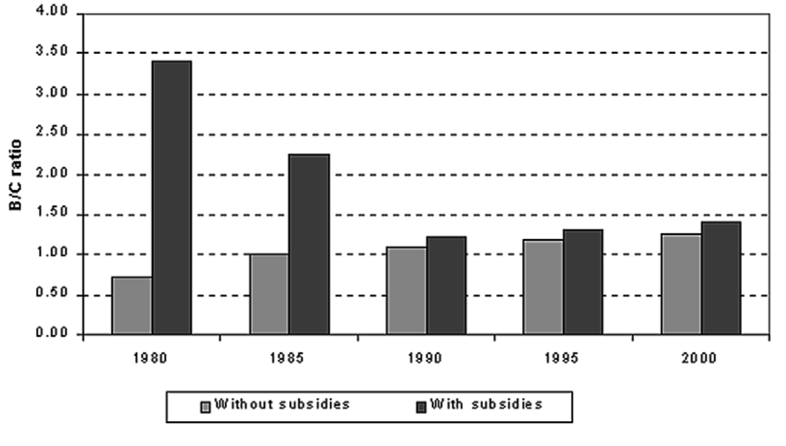

Fig. 4. Evolution of benefit–cost ratio for a typical solar water heater system in the household sector.

3. The Hellenic solar thermal industry

The first units producing solar thermal systems were established in the mid-1970s. The capacity and quality of each industry varied depending on the manufacturer. In 1978, the major manufacturers formed the Hellenic Solar Industry Association (EBHE). The aims of EBHE are the study, promotion, the scientific and technological development of solar energy, the collaboration among its members and their representation in national and international instances. The primary goal of EBHE is the production of high quality and reliable solar thermal equipment, which can provide to the consumer the advantages offered by solar energy.

In order to become a member of the EBHE, a company has to comply with the following:

- It must produce its own solar equipment in a factory belonging directly to this company. The factory must dispose all the licenses required by the law for its operation.
- The production manager must be a mechanical engineer, graduate of a technical university or a technological school of engineering.
- The products have to be tested and certified by accredited laboratories of the European Union, according to the current international (ISO) or European (CEN) standards.
- The measured efficiency of the solar equipment should be higher than a strict threshold value imposed by the EBHE itself.

The solar water heaters and boilers must dispose the CE-mark, according to the law; the test report has to be issued by an accredited testing laboratory.

Due to the above, the participation of a manufacturer to the EBHE is already a quality mark by itself. It is therefore not surprising that the EBHE members control the major part of the domestic solar market and exports. Today, EBHE has 17 member companies. Their size, production capacity and turnover may vary depending on their product range; some industries do not produce only thermal solar systems but other systems too, like air conditioners or central heating system components.

The majority of these companies produce conventional flat plate collectors. The 80% of their annual production covers the domestic market and the remaining 20% is exported. The 90% of exports is towards EU countries and the remaining 10% is exported worldwide.

The ESIF has been created after initiatives of the EBHE. Members of the ESIF are the national associations of 11 country members. ESIF represents its members at the various instances of the European Union; it lobbies and contributes to the preparation of actions for the development and dissemination of solar energy, and contributes to the preparation of European standards related to solar energy applications.

The importance of the EBHE is underlined by the fact that the Hellenic solar thermal market gained a leading position a long time before the publication of the Green Bible of the European Commission and the summits of Rio de Janeiro and Kyoto that enhanced the use of renewable energy sources.

4. Incentive schemes on the demand side

The incentives for the purchase of DHW systems were first applied in 1978, in the form of income tax reduction of 30 000 GRD (1978 rates), by the Law 814 of 1978. The Law 1473 of 1984 increased this sum to 40 000 GRD (1984 rates) [9]. These amounts covered a significant part of the system cost at that time. However, the impact of this incentive became ineffective rather fast due to high inflation during this period (more than 20% annually).

In the early 1980s, soft loans were allocated for the purchase of solar systems, covering up to 70% of the system cost. The Law for Development 1262 of 1982 and its modifications that followed, subsidized solar thermal systems with grants up to 50% of the total system cost. Despite the fact that several bureaucratic procedures created a serious barrier to the efficient application of this law, several collective solar thermal systems were installed, especially in hotels and industries.

At this time the low oil prices, resulting to payback periods of most systems longer than 5 years and the expectations of the expanding natural gas network, have made the solar thermal systems less interesting.

Actually, there are no governmental actions supporting specifically the solar thermal systems. The only support comes from laws and programs supporting the whole renewable energy sector, including also solar thermal applications.

These are [9]:

Law 2364 of 1995 (article 7, paragraph 17) (on the national tax deduction scheme for renewable energies and natural gas). This allows the deduction of 75% of the purchase and installation costs of solar thermal systems from the taxable income of individuals. This is actually the only available incentive for individuals to install solar thermal systems.

The National Development Law 2601 of 1998 (on private investment). This law amends a number of past laws related to support measures and to the development of the national economy, taxation issues, etc. Its main objective is to enhance private investments in Greece in order to promote regional development, as well as the protection of the environment and the conservation of energy. According to this law, all investors purchasing technology related to energy savings, natural gas or renewable energies, can deduce a percentage of 40% from their taxed income. Solar thermal applications belong implicitly in this category.

The Operational Program for Energy. This was established in 1996, covering investment support in the area of renewable energy sources and rational use of energy. Public subsidies came from the European Fund for Regional Development and from the Hellenic government. The program ran until 2000. The subsidies related to solar thermal included only "centralized active solar thermal systems", according to the wording used in the call for tenders. The subsidies ranged from 35 to 55% of the total investment. The subsidy was higher for those projects presenting a higher financial risk. Each project received the 80% of the corresponding subsidy during its construction phase. The remaining 20% was allocated after a year of monitoring the performance of the project, provided that the initial energy goals were achieved.

If not, a part of this 20% was retained, depending on the deviation from the initial performance estimations.

Fifty solar thermal projects were subsidized through this program, from which the 47 were applied in hotels. The 49 applications concern the production of hot water for direct use; only one uses hot water to supply an absorption heat pump used for the air conditioning of a warehouse. Finally, 48 applications use flat plate collectors; evacuated tube collectors are used in only two applications. Fig. 5 gives the cost of the 50 solar thermal projects as a function of the installed collector area. It can be seen that the majority of those projects are below 500 m^2 of collector area. Only few range between 500 and 1000 m^2 and only three projects exceed the 1000 m^2. A simple linear regression yields that the average project cost per m^2 of collector area is of about € 390.

The Operational Program "Competitiveness". This is an undergoing program, established in 2000 for the period from 2000 to 2006. One of its actions is to "provide incentives for private investment related to energy savings, cogeneration, substitution of energy sources and renewable energy sources." In this framework, two types of thermal solar applications are subsidized:

- "Conventional centralized active solar systems" with a subsidy of up to 30% of the total investment and,
- "High efficiency centralized active solar thermal system applications" with a subsidy of up to 40% of the total investment.

The above percentages are currently under revision and may be reduced. The

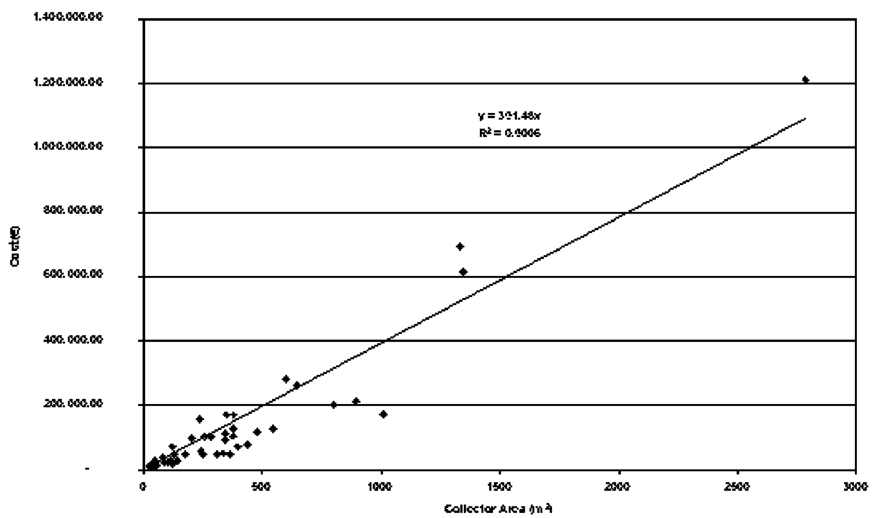

Fig. 5. Collector area and total cost of the projects subsidized by the Hellenic "Operational Program for Energy".

percentage of subsidies will depend again on the energy performance of the system, as it was the case in the frame of the Operational Program for Energy.

In addition to the above, the Center for Renewable Energy Sources (CRES) in Greece, has introduced the third party financing (TPF) scheme. Through this scheme, the following projects have been financed [10]:

- A winery: 308 m^2 of flat plate collectors produce hot water (70–85 °C) for the needs of the bottling unit of the factory. The total cost of the system was € 35 216, 50% of which were subsidized through the Community Support Framework of the European Union and the remaining 50% by the manufacturer of the solar collector through the TPF scheme.
- A dairy products industry: 727 m^2 of solar collectors are used in order to preheat the water entering the steam boiler and also to provide supply water for the washing system (CIP—clean in place) of the factory. This is achieved by combining three types of solar collectors: flat plate collectors with black painted absorber, flat plate collectors with selective absorber and vacuum compound parabolic collectors. The total cost of the system was € 153 000. This cost was covered as follows: € 7000 was the own contribution of the industry, € 11 750 by the Agricultural Bank of Greece in the form of loan and € 134 250 by the Center for Renewable Sources through the TPF scheme.

For these projects, the so-called "Guaranteed Solar Results" contracts have been applied [9]. Under the TPF scheme, the purchase and installation cost of the system is not covered by the user but by an investor. The investor may be the system manufacturer or a third party. When the system starts operating, the investor charges the user with the monthly amount of energy supplied by the system based on a kWh rate agreed when signing the TPF contract. The user becomes the exclusive owner of the system as soon as the initial investment plus the agreed rates are paid back.

From the above, it can be concluded that the Operational Program of Energy had a minor impact on the improvement of the domestic solar thermal market: although the total budget of the program reached € 1.08 billion, the total budget of thermal solar projects was of about € 6.3 million, i.e. 0.58% of the total budget of the program. The collector area installed was 17 759 m^2 over a period of 5 years (1996–2000) i.e. an average of 3552 m^2 of solar thermal collectors annually. During the same period, the annual sales of solar thermal collectors in the country were in average 60 030 m^2. Therefore the Operation Program of Energy contributed only by 6% to the total increase of the solar collector area.

The effectiveness of the Operational Program "Competitiveness" cannot be yet assessed, since the program is in its very early stage. However, taking into account that the percentage of subsidies for solar thermal systems has been reduced (30% in most cases and this may be reduced further—compared to that of 50% of the Operational Program of Energy) and that the administrative procedures for the selection, follow-up and assessment of the projects appear to be heavier (according to the elements provided in the call for tenders), compared to those of the Operational Program of Energy, it is expected that the impact of this program on the installed

solar collector area will not exceed the score of 6% achieved by its predecessor. This percentage is significantly lower than the 20% of annual increase necessary to reach the European target [1].

TPF had a rather low impact, since from 1996 until this date, only two projects were reported to operate through this scheme.

According to the EBHE important incentives on the demand side would be:

- The preservation of the tax deduction incentives for individuals. This is considered as the most efficient incentive form until now and is the one that helped boost solar collector sales in the past.
- The adoption of indirect subsidy via the electricity bills; i.e. the Public Power Corporation would allocate to the consumer a monthly credit on his electricity bill for partial or total coverage of the price of the installed solar collector. The company will benefit from the reduction of the peak electricity demand that will result.

These types of incentives would allow a constant development of the internal market and also the easier replacement of ageing equipment.

Almost all governmental incentives were addressed to the demand side. The only measures that could be considered as incentives on the supply side is the sponsoring of advertising campaigns related to the energy and environmental benefits of solar thermal applications.

The most important advertising campaigns took place in 1984 and 1986 (large-scale televised promotion campaigns) and another, in two phases, over the period 1994–1996 [9].

This second campaign was a collaborative effort between the CRES, the EBHE and the Public Power Corporation. This campaign comprised televised spots and direct mailing of flyers through the Public Power Corporation bills.

The main arguments of this campaign in favor of solar energy were:

- Savings (average expected payback period of a solar water heater between 4 and 6 years).
- Safety (compared with electric water heaters) and trouble-free operation.
- Quality of life (continuous availability of hot water).

The sales of solar collectors increased significantly during the implementation of these campaigns.

5. Future prospects—evaluation of barriers

The prospects for the further development of solar thermal applications in Greece are encouraging, since today they cover only a very small percentage of the energy needs of the country.

The potential for further development of solar energy applications in Greece is

important. According to the energy balance data as of 1998, the total energy consumption of the residential and tertiary sector was 10 629 MTOE, from which 6490 MTOE in form of electricity and 3319 MTOE in form of solid, liquid and gas fuels. The remaining 820 MTOE were covered by biomass (702 MTOE) and solar thermal (118 MTOE). From these figures, it is clear that solar heat covered only 1% of the total energy consumption [11]. The energy production data of solar thermal systems for the year 2000 are as follows: about 99% (1139 GWh) of the solar thermal energy produced was used in the domestic sector (mainly for domestic hot water and marginally for space heating). The remaining was used in the tertiary sector (8.8 GWh) and for industrial applications (1.6 GWh). The above figures illustrate clearly the potential for further development of solar thermal applications.

5.1. Residential sector

Although the solar thermal systems in Greece cover mainly this sector, it still presents important perspectives. The number of households today is estimated to be about 4 000 000. Only 20% of them are equipped with a solar system. The remaining 80% use mainly electrical boilers; only a small percentage uses the central heating boiler also for domestic hot water production. The target of EBHE for the year 2010 is to cover 70% of this potential market. In order to achieve this, 2 000 000 additional systems have to be installed during the coming 9 years. This aim can be considered as realistic, since the 70% target was the penetration of solar systems in the markets of Cyprus and Israel, quite similar to that of Greece, within 10 years of systematic effort. In addition, as already presented in Section 2.5, the space heating water systems (SHWS) present today a B/C ratio considerably higher than 1 and therefore a significant penetration of these systems should be expected in the near future, even without any economic incentives.

Campaigns are also needed in order to increase the awareness of the public opinion and policy makers to the fact that the use of solar thermal systems only for domestic hot water represents only a small fraction of the potential of this technology in the country. Other applications like combined solar thermal space heating and cooling need to be considered urgently. This is clearly illustrated in Fig. 6, from which it can be seen that that more than 70% of the primary energy consumption can be covered by solar thermal systems.

Solar energy can contribute to space heating via centralized or individual systems. Large-scale central solar heating systems with or without interseasonal storage are well developed not only in Northern Europe, especially in Sweden and Denmark, but also in Germany and Austria. These systems deliver heat both for domestic hot water and space heating. The solar fraction (the percentage of the total thermal load covered by the solar thermal system) in these installations can be more than 55%.

Such a system—in a much smaller scale—has been installed and operates in Athens, Greece (the Lykovrissi Solar Village Project—Fig. 7), with a similar performance; the measured solar fraction of the system is of about 55%. A 2-year monitoring period demonstrated that the interseasonal storage system performed better than any other solar space heating system tested in the same housing project [12].

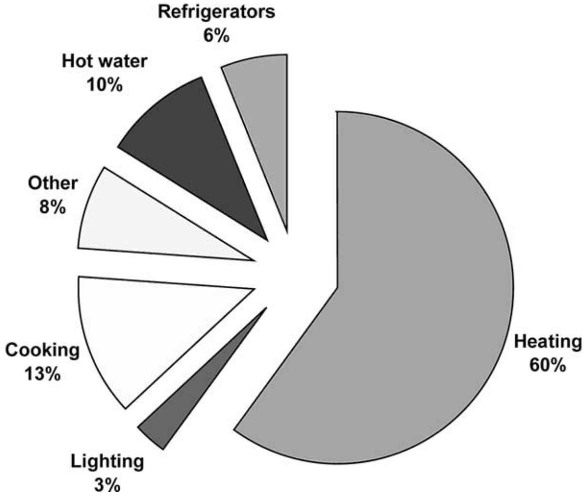

Fig. 6. Energy consumption breakdown in Greek residential buildings (Argiriou et al., [13]).

Fig. 7. The Lykovrissi Solar Village—interseasonal solar thermal plant.

Despite the success of this project however, this system was not replicated in any other housing project.

Although a centralized solar thermal system performs better than small systems, the use of individual systems still remains an interesting alternative. A study focusing on solar thermal applications in Northern Greece, where the weather conditions are the most disadvantageous, has shown that individual combined domestic hot water and space heating systems installed in individual houses can be an interesting investment and operate with an annual solar fraction of about 30% [13]. A preliminary

economic analysis showed that the realization of such an investment in a typical Hellenic household presents a B/C ratio around 0.78, in case that no economic incentives are in place (Table 5). It is therefore obvious that such an investment should be subsidized in order to compensate the related expenditure with the savings from energy conservation. A B/C ratio of the system around 1 implies that approximately 22% of the total investment cost will be covered by subsidies.

The individual solar thermal space heating systems could also be of interest in energy retrofitting of existing buildings, since in many cases, the price of energy provided by a solar system may be lower than the price of the energy saved by adding insulation to the building, all costs taken into account [13].

Cooling is another potential solar thermal market sector. Space air conditioning is a growing demand, which during the last decade contributes significantly to the increase of energy consumption in the building sector, residential and other. Fig. 8 illustrates the sales of packaged air conditioning units in Greece between 1996 and 2000 [14]. This type of units is used mainly in the residential sector and in many buildings of the tertiary sector. From this figure, it can be seen that the sales increased within this period by more than 200% and that the trend of this increase is exponential. The problem is more serious in the Southern European countries, where overheating avoidance measures, effective in northern Europe, cannot solve the problem alone. Solar thermal systems coupled to absorption or desiccant cooling equipment present an interesting solution to this problem. This is because the seasonal but also daily cooling requirements of a building are practically in phase with the output of a solar thermal system. These systems seem to be very promising in rela-

Table 5
Technical assumptions and economic attractiveness of large solar applications in the Greek buildings sector (all costs referred to 1995 constant prices)

	Residential heating	Residential cooling	Tertiary cooling
Assumptions			
Application	Household with a surface of 90 m^2	Building with a surface of 150 m^2	2700 m^2 of solar collectors
Diesel conservation (toe/y)	0.386	0	25.5
Electricity conservation (toe/y)	0.137	4.17	86
Investment cost (€)	3936	10 592	1 188 497
Electricity cost (€/toe)	930	930	930
Diesel cost (€/toe)	440		440
Subsidy (as a percentage of the investment cost) (%)	0	0	40
Load coverage (%)	35	100	61
Results			
NPV (€)	−875	30 064	226 027
B/C ratio	0.78	4.05	1.32

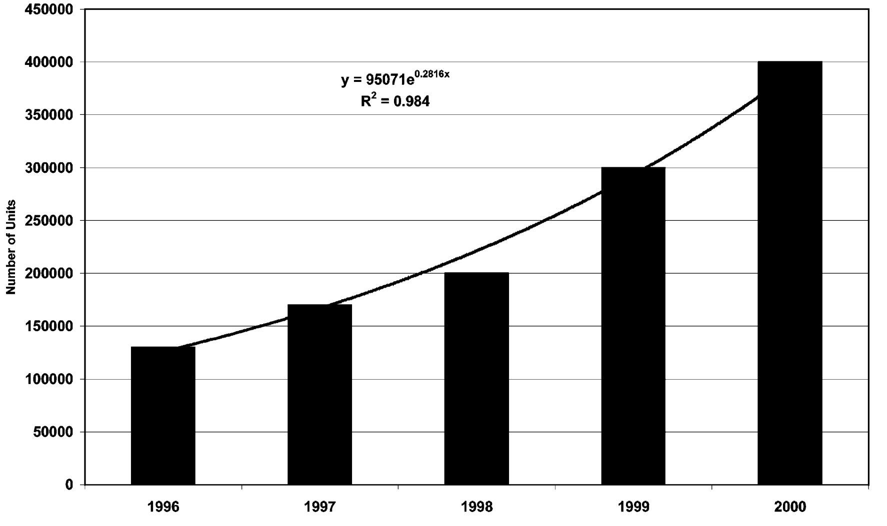

Fig. 8. Sales of packaged air conditioning units in Greece and trendline.

tively large buildings used for residential purposes (Table 5). Specifically, a preliminary analysis showed that the installation of such a system in a residential building located in Athens presents a *B*/*C* ratio of 4, constituting thus one of the most attractive solar applications. Therefore the solar heat can be used directly and the need of energy storage is minimized. Successful applications of space air conditioning systems are already available, however further dissemination and research effort is needed.

Such a successful application in Greece is the use of solar thermal systems for space cooling of the stock warehouse of the factory of Sarantis S.A., a cosmetics industry, located at about 50 km north of Athens. The solar system consists of 2700 m^2 tube-fin, flat plate collectors. The absorber of the collectors is covered with selective paint. The collectors supply the regeneration chamber of silica-gel adsorption chillers, which maintain the temperature of the warehouse at 27 °C [10]. This application was subsidized by 40% of the total investment cost and presents a *B*/*C* ratio of 1.32 (Table 5). Without this significant subsidy, the *B*/*C* ratio of this investment would have been around 0.79.

The buildings of the tertiary sector represent another potential market for solar space heating and cooling applications let alone the hotel sector that has not been exploited yet.

5.2. Industrial applications

About 30% of the total requirements of the industrial sector in oil are consumed in low to middle temperature thermal applications. These are particularly suited to solar thermal systems. The increasing tendency in oil and natural gas prices creates a favorable environment for the penetration of thermal solar systems in industrial

applications. Economies of scale combined to TPF and the improvement of the products and the services offered by the solar thermal manufacturers will further enhance this penetration.

5.3. Potential barriers

The potential barriers in the further development of the Greek solar market should be distinguished in two categories: the first category comprises the simple domestic solar water heaters and the second, larger applications combining not only the production of domestic hot water but also space heating and cooling.

For the first category of applications, potential barriers would be one or a combination of some of events like a constant decrease in oil prices, a significant depreciation of the dollar against the Euro or a dramatic change in the taxation policy of the EU countries on oil. At this time, none of the above seems likely to occur.

The barriers for the development of the second type of applications are the following:

- The lack of public awareness in solar space heating and cooling applications. This is due to the limited number of real-scale applications in Greece. In order to overcome this problem further demonstration projects are required.
- The important initial investment cost. Although, as already mentioned, 75% of the system purchase and installation cost is deducted from the taxed income, this parameter still remains a problem, taking into account the important cost of real estate in the country and the average incomes. Further incentives and subsidies, through flexible administrative schemes are suggested. Also, the possibility for special low interest rate loans for such installations could contribute to overcome this barrier.
- The degree of urbanization of the major Greek cities that does not allow easily the implementation of energy retrofit measures that will include centralized solar thermal systems.
- The architectural type of the Mediterranean buildings. The lack of tilted roofs does not facilitate the integration of solar collectors.
- Lack of infrastructure for centralized plants. Many large-scale solar heating plants in Northern Europe use existing district heating networks. Such networks are not common in southern European countries and their installation increases the required investment cost.
- The intensive promotion of the use of natural gas may have a negative impact on the further development of solar thermal applications. Greece has procurement contracts and is constrained to import annually 2.8 billion m^3 of natural gas from Russia and at least 0.51 billion m^3 from Algeria. The natural gas is commercialized through the Public Gas Corporation (PGC). The sales of PGC for the year 2000 were 1.9 billion m^3 i.e. the 57% of the purchase quotas [15]. The PGC promotes strongly the use of natural gas in order to cover the remaining 43%.

6. Conclusion

The Hellenic solar thermal market sector is one of the most developed ones worldwide. A review of the conditions under which this development occurred, shows that this was due mainly to the efficient collaboration between the domestic solar energy industries, the quality assurance procedures applied and the ability of the manufacturers to penetrate early with quality products to emerging markets abroad. Subsidy policies, mainly on the demand side, contributed also during the early years, but do not seem to be very effective any more. On the other hand, some of the related technologies are mature enough in order not to require subsidies.

Despite this development, there is still an important part of the energy needs that could be covered by solar thermal systems, since their contribution to the energy balance of the country remains marginal. For the further enhancement of this market it is necessary to:

- Promote through demonstration projects and financial support applications other than the commonly used production of domestic hot water. Such fields are space heating and cooling but also industrial applications.
- Promote through demonstration projects and financial support the utilization of solar thermal systems other than the individual natural circulation systems. Emphasis should be given on large-scale solar thermal systems, based on the very interesting experience of their use in Northern Europe. To this end, it is necessary to demonstrate the use of large-scale solar thermal systems that can be used to cover both the needs of heating and cooling. Although a preliminary analysis showed that solar cooling applications are economically viable without subsidies, financial support is suggested in the early stages for demonstration projects.
- Simplify the administrative procedures required for the demand and follow-up of governmental subsidies for selected applications.
- Establish permanent awareness campaigns on the benefits of solar thermal applications.

Such actions will further contribute to the European target of 100 million m^2 of collector area by the year 2010 [1].

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